Design and Integration of a Scent Delivery System in the Computer Assisted Rehabilitation Environment (CAREN)

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Abstract

The Computer Assisted Rehabilitation Environment (CAREN; Motek Medical BV, Amsterdam, The Netherlands) located at the Naval Health Research Center (NHRC) is an immersive virtual environment and motion analysis laboratory designed for interactive rehabilitation and research of human performance in a controlled and repeatable environment. While NHRC's CAREN was originally equipped with audio, video, and motion capabilities, the system did not provide any type of olfactory immersion capability. As such, our research team determined olfactory simulation to be a strong enhancement for improving the immersion capabilities of NHRC's CAREN. The objective of this development was to design and integrate a functional scent delivery system, which can release fragrances that associate with current and future scenarios in the virtual reality environments. Several custom scent delivery system manufacturers were investigated to achieve this goal. Upon completion of the investigation, the scent system was designed using CAREN system compatible components and integrated into NHRC's CAREN. The scent delivery system at NHRC releases six different fragrances in a reliable and time-controlled manner. The scent simulation increases immersion into the virtual environment, and thus increases the research and rehabilitation impact of the NHRC CAREN. With this increased effectiveness comes the improved ability to research methods of rehabilitation for our servicemembers.

Introduction

The Computer Assisted Rehabilitation Environment (CAREN; Motek Medical BV, Amsterdam, The Netherlands; Figure 1) located at the Naval Health Research Center (NHRC) is an immersive virtual environment and motion analysis laboratory. It is designed for interactive rehabilitation and research of human performance in a controlled and repeatable environment. The Department of Defense uses the CAREN system for clinical rehabilitation and research at three locations (in addition to NHRC): Walter Reed National Military Medical Center, Brooke Army Medical Center, and the National Intrepid Center of Excellence. The primary purpose of NHRC's CAREN system is to conduct research for warfighter performance and the advancement of treatment and rehabilitation practices. NHRC creates and tests accelerated rehabilitation programs and conducts physical and cognitive performance testing under virtual conditions relevant to the warfighter.

Figure 1. Computer Assisted Rehabilitation Environment (CAREN).

The CAREN requires control software in order to manipulate and monitor the hardware components, activate events, record information, and create virtual scenarios. The CAREN D-Flow control software allows the operator to create, modify, and operate virtual scenarios. It incorporates different modules from which to manipulate and monitor the hardware components, activate events, and record information. While NHRC's CAREN was originally equipped with audio, video, and motion capabilities, the system did not include any type of olfactory immersion capability. In order to integrate this technology and increase the immersion capabilities of the virtual environment, a scent delivery system was needed. Furthermore, due to the complexity of the CAREN system, a custom engineered scent delivery system was required (ScentAir Technologies Inc., Charlotte, NC; Figure 2). ScentAir Technologies, Inc. was selected to provide NHRC with this custom scent system. ScentAir Technologies, Inc., along with many other scent providing companies, has several off-the-shelf items capable of delivering a single-controlled

Figure 2. Custom-engineered scent delivery system.

scent into a space ranging from 2,000 to 500,000 square feet. While this is acceptable for most applications (e.g., hotels, businesses, shops), NHRC would require a much more complex system which only ScentAir Technologies, Inc. could provide at the time. The purpose of this paper is to report the method for designing and integrating this scent delivery system into NHRC's CAREN system.

Method

Before design of the scent delivery system could begin, the type and quantity of fragrances or scents had to be determined. ScentAir Technologies offers hundreds of types of fragrances, and it also has a category of "Unusual Scents Used in Exhibits, Simulation, and Military Applications," which satisified NHRC's needs to create more realistic military relevant scenarios (see Appendix A). After examination of current and planned CAREN scenarios, it was determined that six different scent chambers would suffice, giving NHRC's CAREN the ability to release six different scents during a CAREN application. The scent chambers were preloaded from the factory with the following scents: 1) Earth, 2) Burning Wood, 3) Pacific Breeze, 4) Barnyard, 5) Oily Machinery, and 6) Cordite. Of note, the scent cartridges can be exchanged for others if new scents are needed for different scenarios. Once the quantity and types of scents were determined, the hardware design of the scent delivery system was established. Two key requirements were essential in the design of this scent delivery system; the system would need to interface with the CAREN D-Flow software, and this interface must allow for scents to be delivered in a reliable and time-controlled manner. The ScentAir Technologies scent delivery system satisfied both of these requirements. This scent delivery system impregnates low-pressure air with specific fragrances using a series of solenoid valves, scent chambers, and tubing (Figure 3). A dry air supply at 30-60 psi (required to input into the scent system) is powered with one 115-V AC (alternating current) outlet. The scented air then passes into the CAREN via plastic tubing. The tubing should be placed near the subject for more focused scent delivery. At NHRC, the tubing is placed under the screen and angled up toward the subject.

A Phidgets model 1012 PhidgetInterfaceKit (Phidgets Inc., Calgary, Alberta, Canada; Figure 4) is used to control the solenoid valves (Granzow Inc., Charlotte, NC; Figure 5) and release scents when programmed in the CAREN D-Flow software. A Phidgets Inc. circuit board was required as it is the only brand of circuit board compatible with the CAREN D-Flow software at this time. With the Phidgets model 1012 PhidgetInterfaceKit controlling the scent delivery system, only a small amount of programming was needed to incorporate this scent delivery into D-Flow applications.

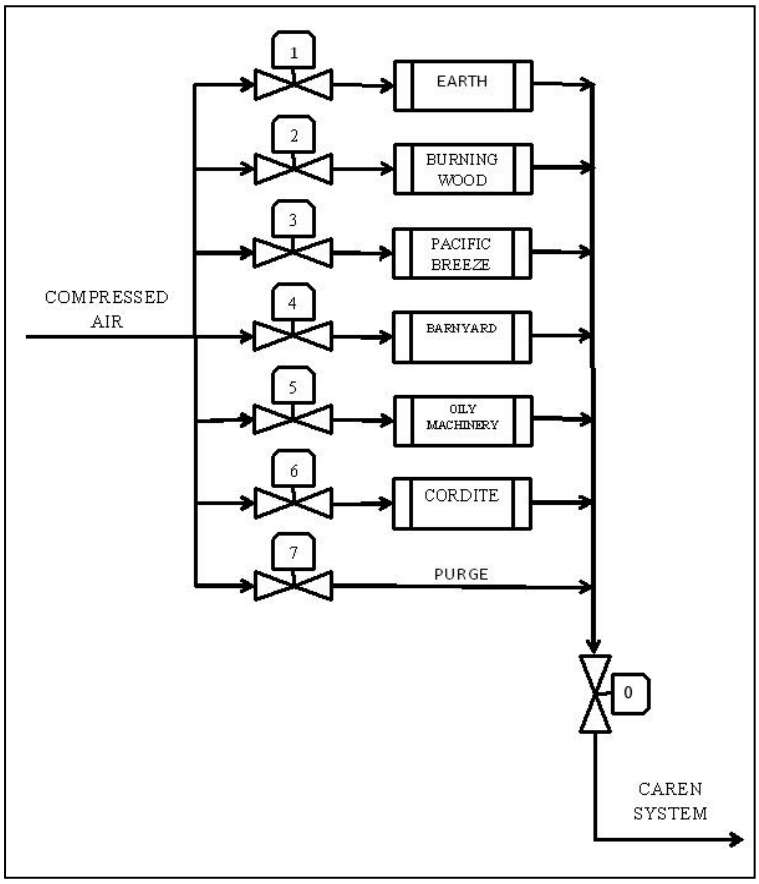

Figure 3. Scent delivery system process flow diagram. Numbers represent each solenoid valve to control the flow of the compressed air into each fragrance chamber.

Phidgets PhidgetInterfaceKit Programming in D-Flow

The Phidgets 1012 PhidgetInterfaceKit can control up to 16 devices via digital signals. Each digital signal can produce up to 30-V DC (direct current) and 2 amps. The output of this control board acts as a switch to the ground, so the circuit itself needs an external power supply. The scent delivery system was provided with a 5-V DC external power supply in order to control the 5-V DC solenoid valves supplied with the scent delivery system. Each

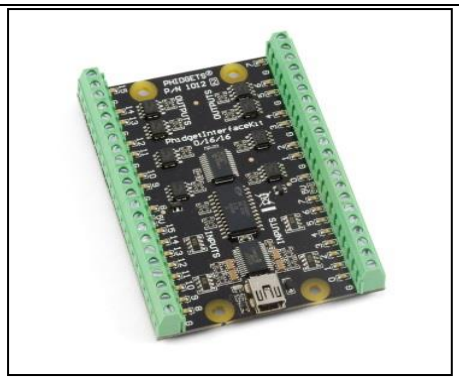

Figure 4. Phidgets model 1012 PhidgetInterfaceKit.

Figure 5. Solenoid valve.

solenoid valve in the scent delivery process flow diagram is labeled with a number corresponding to its digital channel in the Phidgets 1012 PhidgetInterfaceKit. If a signal is sent to a digital output channel on the Phidgets board (programmed within D-Flow), the respective solenoid valve for that channel will open. As diagrammed in Figure 3, the scent delivery system can route low-pressure, compressed air through the series of fragrance chambers to produce scent. When programming the scent delivery system in D-Flow, Channel 0 is used as the main ON/OFF solenoid valve for the scent delivery system. Channel 7 is a purge air option where unscented air can be passed. This purge valve should always be open unless a scent is being released. When a scent is released, the purge solenoid valve should be temporarily closed while the desired scent valve is open. For example, if an "Earth" scent was desired, the Channel 7 solenoid valve would be closed temporarily while Channel 1's solenoid valve was opened. After the desired amount of scent was released, the Channel 1 solenoid valve would be closed, and the Channel 7 solenoid valve would reopen. The purge is very important as it continues to push scent-charged air from the scent delivery system and prevents scents from sitting within the tubing that delivers scented air to the CAREN system. If scents sit within the tubing, they will comingle and taint each new scent being delivered. The desired amount of scent to release must be determined by the application programmer and may vary for each CAREN system and scenario. Refer to Appendix B for an example of Lua scripting (The Pontifical Catholic University of Rio de Janeiro, Brazil) used to trigger the release of a scent. Note that the longer the tubing, the longer it will take for scents to reach the subject; thus, scent release must be programmed accordingly.

Safety

A pressure vessel is a storage tank or vessel that has been designed to operate at pressures above 15 psi. Cracked and damaged vessels can result in leakage or rupture failures. The scent delivery system at NHRC is comprised of six pressure vessels confined in a shielded enclosure. It is essential that, while charged with air pressure, the sliding doors on the scent system enclosure remain closed.

Personal protective equipment should be worn while servicing the scent delivery system. Also, while performing maintenance or changing scents inside the scent enclosure, the main air line feeding the system should be disconnected, and the system should be depressurized before opening the enclosure. The scent system is also designed with a pressure relief valve, which prevents overpressure of the system during operation.

The discharge tube from the scent delivery system to the CAREN system is a low-flow, low-pressure discharge air discharge line. The scents disperse very quickly into the air in the simulation area and should never be pointed directly at a subject or patient.

Results

The scent delivery system requires very little setup for installation. The required installation equipment includes a dry air supply input to the scent system, power supply, output tubing, and a Phidgets control board to interface with the CAREN D-Flow software. Programming of the scent delivery system is simple using the CAREN D-Flow software. Attaching scents to objects or events occurring in the simulation can release them automatically, making them a fully automated system. Lua scripts can also be used to control the release of scents within the virtual scenarios.

The scent delivery system at NHRC is a very effective method of increasing immersion into the CAREN system. For example, releasing a "Cordite" scent after gunfire may help the subject or patient feel like they are firing a real weapon (Figure 6). A continuous output scent of "Pacific Breeze" during a scenario where subjects are maneuvering a boat through the water can make them feel like they are really in the ocean. Further, having the scent of earth or burning wood can promote immersion into an environment where those fragrances are viable. The scent system has unlimited possibilities for types of scents and how they can be used.

Figure 6. Example of subject walking in the CAREN system with a simulated weapon during cordite scent release.

Appendix A. Military-Specific Scent List from ScentAir Technologies, Inc.

Unusual Scents Used in Exhibits, Simulations, and Military Applications			
Environmental		**Mood**	
152	Musty	275	Dinosaur Dung/Iraq
160	Earth	402	Leather
681	Redwood Forest	1014	Spoiled Beef
732	Skunk	1410	Swagger (leather & tobacco)
873	Rainforest/Fresh Grass	1522	Raw Sewage
912	Cedar	1525	Sandalwood
947	Wood Fire	1526	Patchouli
956	Evergreen	1531	Buddhist Temple (incense)
1622	Burnt Wood/Grill	1632	Rotting Garbage
1634	Mercaptan/Natural Gas	1637	Barnyard/Livestock
1655	Seashore	1644	Roasting Meat
1855	Pacific Breeze	1913	Street Waste
1928	Charcoal Pit	**Body**	
2037	Marina	1623	Decaying Flesh
2061	Campfire	1624	Urine
Mechanical / Munitions		1625	Human Feces
133	Engine Exhaust	1636	Gangrene
170	Gunpowder	1639	Dung
218	Sulfurous Volcano	1643	Burnt Flesh
219	Burning Rubber	1645	Dead Body
243	Diesel Exhaust	1690	Vomit
252	Oily Machinery/Hydraulic Fluid	**Food**	
1432	Cordite	1095	Coffee
1433	Burnt Wire	1633	Curry
1635	Oily Chemicals/Industrial	1644	Roasting Meat
1638	Gasoline	1663	Black Pepper
1640	Burning Vehicle	1664	Cumin
1650	Tar Asphalt	1680	Rosemary Focaccia Bread
1680	Car Bomb	1990	Garlic
1905	Turpentine	1992	Mesquite BBQ

Appendix B. Lua Script for Release of Scent

Description

The Lua script below is a simple design, which enables one to test the scent delivery system for functionality. Each scent is labeled in a parameters module and given a checkbox (Figure 7). When the box is checked for the specific scent or purge, then the corresponding scent will be released to the CAREN system. If no box is checked, then the script will close all valves in the scent delivery system and not push any scent or purge air to the CAREN system. Clicking the "Reset Parameters" button will also close all valves and stop the distribution of scents to the CAREN system as well.

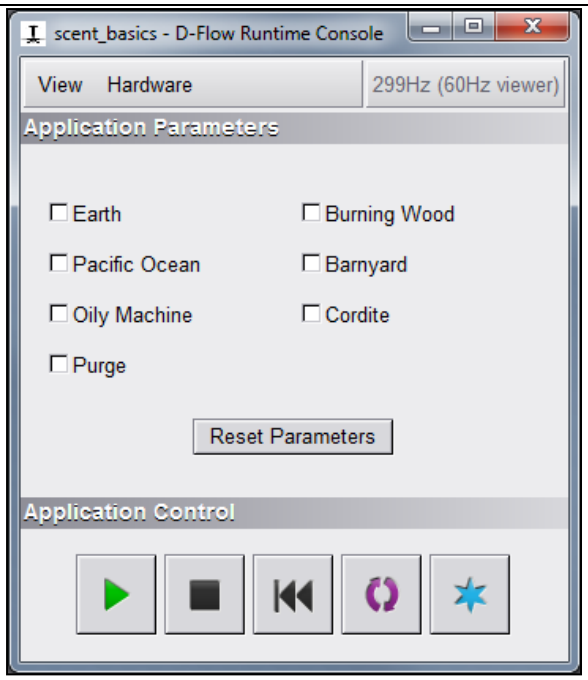

Figure 7. Parameters checkbox.

Lua Script

```
-- input values
    doEarth = inputs.get("InEarth")
    doBurnWood = inputs.get("InBurnWood")
    doPacOcean = inputs.get("InPacOcean")
    doBarnyard = inputs.get("InBarnyard")
    doOilyMchn = inputs.get("InOilyMchn")
    doCordite = inputs.get("InCordite")
    doPurge = inputs.get("InPurge")

```

```
10  -- initial values
11      if      action() == "Start"
12      then    output = 0
13              earth = 0
14              wood = 0
15              ocean = 0
16              barnyard = 0
17              machine = 0
18              cordite = 0
19              purge = 0
20      end
21      if      1 == doEarth or
22              1 == doBurnWood or
23              1 == doPacOcean or
24              1 == doBarnyard or
25              1 == doOilyMchn or
26              1 == doCordite or
27              1 == doPurge
28      then    output = 1
29      end
30      if      0 == doEarth and
31              0 == doBurnWood and
32              0 == doPacOcean and
33              0 == doBarnyard and
34              0 == doOilyMchn and
35              0 == doCordite and
36              0 == doPurge
37      then    output = 0
38      end
39      if      1 == doEarth
40      then    earth   = 1
41      else            earth   = 0
42      end
43      if      1 == doBurnWood
44      then    wood    = 1
45      else    wood    = 0
46      end
47      if      1 == doPacOcean
48      then    ocean   = 1
49      else    ocean   = 0
```

```
50      end
51      if      1 == doBarnyard
52      then    barnyrd = 1
53      else    barnyrd = 0
54      end
55      if      1 == doOilyMchn
56      then    machine = 1
57      else    machine = 0
58      end
59      if      1 == doCordite
60      then    cordite = 1
61      else    cordite = 0
62      end
63      if      1 == doPurge
64      then    purge   = 1
65      else            purge   = 0
66      end
67      -- set output values
68      outputs.set("Output", output)
69      outputs.set("Earth", earth)
70      outputs.set("BurnWood", wood)
71      outputs.set("Ocean", ocean)
72      outputs.set("Barnyard", barnyrd)
73      outputs.set("OilyMachn", machine)
74      outputs.set("Cordite", cordite)
75      outputs.set("Purge", purge)
```

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